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**Peak forelimb ground reaction forces experienced by dogs jumping from a simulated car boot**

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17 **Abstract**

18

19 Many dog owners allow their pets to jump out of a car boot, however, to date  
20 there has been no study that has investigated whether this places dogs at risk  
21 of injury. The aim of this study was to investigate the relationship between  
22 height and peak vertical ground reaction force (vGRF) in static start jumps.  
23 Fifteen healthy adult dogs performed three jumps from a platform that  
24 represented common vehicle boot sill heights (0.55m, 0.65m, 0.75m), landing  
25 on a single force platform. Kinetic data ( $F_x$ ,  $F_y$  and  $F_z$ ) were normalised for  
26 body weight and analysed via a one-way repeated analysis of variance  
27 (ANOVA) and pairwise post-hoc tests with a Bonferroni correction applied.  
28 There was a significant difference in peak forelimb vGRF between both the  
29 0.55m ( $27.35 \pm 4.14$  N/Kg) and the 0.65m ( $30.84 \pm 3.66$  N/Kg) platform ( $p=0.001$ )  
30 and between the 0.65m and 0.75m ( $34.12 \pm 3.63$  N/Kg) platform ( $p=0.001$ ).  
31 There was no significant difference in mediolateral or craniocaudal forces  
32 between the heights examined. These results suggest that allowing dogs to  
33 jump from bigger cars with a higher boot sill may result in augmented levels of  
34 loading on anatomical structures. Further research is required to investigate  
35 the kinematic effects of height on static jump down and how peak forelimb  
36 vGRF relates to anatomical loading and subsequent injury risk.

## Introduction

The percentage of households in the UK with pet dogs is estimated to be 24%, with a population of around 8.5 million [1]. There are many reasons why a dog will leave the home (trip to local park, vet visits, holidays, day boarding, attending competitions or shows) which usually necessitate vehicular transportation. UK legislation stipulates that dogs must be restrained when travelling in a vehicle [2], both for the driver and dog's safety. In addition, published guidance to handlers outlines specific environmental requirements when transporting a dog in a vehicle [3, 4], yet neither provides direction on appropriate methods of entry or exit into the back seat or rear compartment (boot); the areas in which many owners confine their dogs [5]. Techniques vary from manual lifting, allowing the dog to jump in and out, or employing the use of a ramp. However, no studies currently exist that investigate the reasons to opt for a particular method or the frequency with which each is used.

Lifting a dog can pose a risk of injury to both the owner and dog, dependent on the technique used. For example, lifting an animate and unpredictable object (such as a dog, weighing up to 50 kilograms) scores highly in a workplace manual handling risk assessment particularly when twisting/stooping postures are employed [6]. It is noteworthy that much evidence is available in the human field investigating the prevalence and risk factors associated with back pain [7–9], particularly in relation to lifting [6]. Guidance on the safe load limits when lifting has been published [6], and therefore, from a health and safety perspective lifting larger dogs should preferably be avoided.

With a wide variety of vehicle boot sill heights present in the UK [10], it is unclear whether these heights have a direct impact on the risk of injury. In allowing dogs to jump unaided out of vehicles, owners may be inadvertently predisposing their dogs to the development of musculoskeletal pathologies. Some studies have explored the biomechanics of competitive jump landings in dogs [11–14], however minimal quantitative canine studies investigating the effects of jump landing exist when investigating static start jump-downs. Given

72 the paucity of research in this area, it is important to consider the  
73 biomechanical implications of jumping from a stationary position from a range  
74 of heights.

75

76 There are no studies of dogs that directly investigate the relationship between  
77 vertical ground reaction force (vGRF) and forelimb injury, however, equine  
78 studies have attempted to relate the action of jumping to the injury of three  
79 specific forelimb tendons [15]. Clear distinctions in loading were identified, with  
80 the highest peak loading occurring at the superficial digital flexor tendon  
81 (SDFT). Although the mechanical and functional properties of this tendon have  
82 been reported [16] and in vitro studies suggest the mechanisms of  
83 microtrauma [17, 18], no further clinical studies have been published for  
84 comparison. Out of the three jump heights investigated (0.8m, 1.0m and 1.2m),  
85 only the SDFT tendon absorbed substantially more force as height increased.

86

87 Evidence relating to peak vGRF experienced by dogs jumping from a static  
88 start would be of key interest to the veterinary profession in providing a clearer  
89 picture of the aetiology of common musculoskeletal pathologies (osteoarthritis,  
90 elbow dysplasia, hip dysplasia), where disease expression is reported to be  
91 affected by environmental variables [19]. If there is a significant effect of height  
92 on peak vGRF when dogs perform a static start jump, this would provide  
93 suitable evidence to recommend the use of prevention measures such as  
94 ramps.

95

96 Many studies have investigated the aetiology of conditions such as  
97 osteoarthritis (OA) [20–22] with many concluding that there are both normal  
98 and pathological adaptations of articular cartilage to joint loading. One study  
99 compared bone specimens of dogs with fragmented medial coronoid  
100 processes (FMCP) against those without (n=38) to demonstrate a significant  
101 relationship between fatigue micro-damage and FMCP [23]. Given that the  
102 repeated loading of bone leads to the formation of micro-cracks within  
103 mineralised tissue [24, 25], and with a paucity of specifically designed studies,  
104 it is plausible that elbow dysplasia could be partially a manifestation of  
105 repeated loading of the forelimbs when jumping from vehicles. It has been

106 highlighted that increasing the load on ex-vivo elbow joints brings about  
107 significant changes in several joint space measurements [26].

108

109 Several studies have examined the kinematics and kinetics of dogs jumping  
110 over hurdles [11, 13, 27, 28], but not from a static start jump down. However,  
111 as jumps from a static start are commonly performed by dogs (from furniture,  
112 cars etc.), biomechanical studies are required to inform whether dogs should  
113 be allowed to perform these activities.

114

115 The aim of this study was to investigate the effect of height on peak forelimb  
116 vGRF when dogs perform a static start jump from a platform of equivalent  
117 height to a car boot. Heights were selected to represent a range of boot heights  
118 that exist in common car models. It was hypothesised that jumping from the  
119 higher platforms would result in increased peak vGRF due to the increased  
120 length of the aerial phase and the consequent change in downwards velocity  
121 (due to gravitational acceleration) at impact [13].

122

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## **Materials and Methods**

126 This study was approved by the ethics committee at University Centre,  
127 Hartpury and all work was conducted in line with institutional ethical guidelines.  
128 Fifteen dogs were recruited from a convenience sample through advertising at  
129 local agility clubs and dog walking groups. Information sheets were provided  
130 to owners along with a consent form. On receipt of signed consent forms, the  
131 medical history of each canine participant was requested (permission granted  
132 by owner) from their registered veterinarian. This enabled verification that  
133 participants met the inclusion criteria. Consent from owners was also gained  
134 verbally on the day at each stage of data collection once the research activity  
135 had been re-explained to them.

136

137 Immediately prior to data collection, each canine participant was physically  
138 assessed by the primary researcher (ACPAT Chartered Physiotherapist) to  
139 ensure that no contraindications to participation were present (e.g. lameness,  
140 musculoskeletal pain response, altered neurological state). All canine  
141 participants were visually gait assessed for a minute at walk and trot for  
142 soundness, together with spinal and peripheral limb palpation to exclude the  
143 presence of anatomical tenderness suggestive of pain. Knuckling testing was  
144 performed on all limbs since neurological deficit can affect gait parameters [29]  
145 and each peripheral joint (including the scapulothoracic articulation) was  
146 passively moved through the full range of motion to verify that no joint or soft  
147 tissue restrictions were present.

148

### *Inclusion and Exclusion Criteria*

149 Dogs were excluded from the study if they were less than two years of age, as  
150 skeletal maturity of dogs occurs between the ages of 10 to 12 months and  
151 sexual maturity between seven and 21 months [30]. No upper age limit was  
152 set, however dogs were excluded if they had an underlying musculoskeletal  
153 pathology or undiagnosed lameness, since these are known to alter gait  
154 patterns [31–33] and may increase injury risk. Given this research  
155 necessitated subjects performing multiple jumps and additionally that 'long and  
156

low' conformation can predispose to intervertebral disc extrusion [34, 35], chondrodystrophic breeds were excluded from the study. In line with other studies [11, 12], guidelines provided by the UK Kennel Club outlining specific dog height categories [36] in agility competition were utilised to inform the inclusion criteria, with consideration taken for the specification of the three jumping related obstacles (hurdle, table/pause box, hoop tyre). Given that dogs classed in the medium height category are not permitted to jump from heights higher than 0.45m, 0.40m and 0.55m for each of these obstacles respectively, only dogs with a leg length greater than 0.43m were included in the study. Although it is appreciated that dogs can be unpredictable, those without basic obedience skills (being able to sit and wait until told to move) were also not recruited.

169

#### 170 *Study Population*

In order to account for potential sources of variation between dogs, baseline recording of breed, age, gender, weight (measured within the week of data collection) and forelimb length (measured from the distal phalanges to the top of the scapulae) were measured and documented. Nine breeds of dog and one mixed breed dog were recruited with ages ranging from two to nine years (mean  $5.9 \pm 2.39$  years). Eight dogs and seven bitches were included of body mass ranging from 13.8 kg to 33.2 kg (mean  $22.29 \pm 5.26$  kg). Forelimb length (measured to the withers) of the participants ranged between 0.45m and 0.68m (mean  $0.57 \pm 0.07$ m). Breeds included were Belgian Shepherd (4), Border Collie (3), Labrador Retriever (1), Flat Coated Retriever (1), Cocker Spaniel (1), English Springer Spaniel (1), Tibetan Terrier (1), Hungarian Vizsla (1), Bavarian Mountain Hound (1) and Crossbreed (1).

183

#### 184 *Jump Platform*

A height adjustable, stable platform (0.9m by 1.1m) was constructed from a steel and aluminium alloy frame with a stiff medium-density fibreboard (MDF) top-board insert (Figure 1). Interchangeable platform leg lengths enabled three platform heights (0.55m, 0.65m and 0.75m) to be constructed. Setting 0.1m linear increments enabled representation of the spectrum of vehicle boot sill heights being investigated [10]. Non-slip rubber-backed carpeting was placed



191 underneath and on top of the platform with their thicknesses taken into account  
192 to ensure the overall jump down heights were 0.55m, 0.65m and 0.75m.

193

#### 194 *Kinetic Data*

195 The platform was positioned immediately in front of a single AMTI (Advanced  
196 Mechanical Technology Incorporated® MA, US) force plate of dimensions  
197 400mm x 600mm so that vertical ( $F_z$ ), craniocaudal ( $F_y$ ) and mediolateral ( $F_x$ )  
198 forelimb landing ground reaction forces could be recorded. A capture rate of  
199 500Hz and a time period of 10 seconds were used to ensure effective data  
200 collection [13]. Non-slip rubber matting was placed over the force plate and the  
201 surrounding area to ensure that dogs did not slip on landing. Two-dimensional  
202 video recording (Canon EOS 600D, 1280x720, 60fps) of each trial took place  
203 to enable confirmation of the validity of trials. The camera, mounted on a  
204 tripod, was positioned 3 metres immediately lateral to the force plate.

205

#### 206 *Experimental Protocol*

207 In addition to the gait assessment, a five minute warm-up (walking and trotting)  
208 of each individual participant was performed to increase vascularisation and  
209 reduce transient joint stiffness [27]. Each dog was instructed by its owner to  
210 ascend a ramp onto the platform. As an acclimatisation procedure and  
211 individual pilot study, each dog was instructed to sit on top of the platform in a  
212 pre-determined start zone located towards the front edge of the platform,  
213 facing forwards towards the force plate. The dog was commanded to sit and  
214 stay while the owner positioned themselves four metres in front of the platform.  
215 The force plate was configured and armed, the video recording commenced  
216 and the researcher signalled to the owner to call their dog to jump off the  
217 platform.

218

219 A successful trial was classified as one in which the first limb to contact the  
220 ground (trailing limb) landed clearly within the rectangular target zone of the  
221 force plate. This was a rectangular area (outlined using masking tape, Figure  
222 1.) denoting the position of the force plate. For all trials, both forelimbs  
223 contacted the force plate. Owing to variance in morphology and conformation,  
224 altered postures when jumping can occur between dogs [12]. Therefore, to

225 ensure that the trailing forelimb landed consistently within the boundaries of  
226 the force plate, the jumping style of each dog required observation. If on the  
227 acclimatisation jump a dog did not land in the middle of the force plate, the  
228 platform was then moved forward or back in increments of 0.01m for a second  
229 acclimatisation jump [13]. The range of distances used was from 0.26m to  
230 0.47m (mean  $0.38 \pm 0.05$ ). Once a successful trial was observed this counted  
231 as part of data collection and subsequent trials continued with the same  
232 configuration.

233

234 Dogs were required to complete three valid trials at each platform height.  
235 Comparable studies have recorded five trials [27], however given the nature  
236 of the experimental task and the height of the platforms, for ethical reasons  
237 only three trials were performed. The order in which a participant attempted  
238 the two lower platform heights was randomised and a five-minute break was  
239 scheduled between each trial in an attempt to remove any fatigue or potential  
240 cumulative joint loading effects. After the 0.55m and 0.65m platform trials,  
241 each subject was then considered for the 0.75m platform height trial. This third  
242 platform height was only permitted with explicit verbal consent of the owner  
243 and if the researcher was willing to proceed after observation of the individual  
244 dog's previous trials. It is appreciated that true randomisation in relation to the  
245 order of the three platform heights did not occur, however the method used  
246 was felt to be justified on ethical grounds.

247

#### 248 *Statistical Analysis*

249 The kinetic data collected (mediolateral force (Fx), craniocaudal force (Fy) and  
250 vertical force (Fz)) were transferred to Microsoft® Excel® for Mac Version  
251 14.5.3. Normalisation of ground reaction force (GRF) [37] by body mass (kg)  
252 was performed. A mean value of the three normalised peak GRF values (for  
253 Fx, Fy and Fz per platform height) was calculated for each dog (N/Kg). All  
254 data were analysed in SPSS Statistics (Version 23) To test for normality, a  
255 Kolmogorov-Smirnov Test was performed and data were found to be normally  
256 distributed ( $p > 0.05$ ). A one-way repeated measures analysis of variance  
257 (ANOVA) was used to test for statistically significant differences between the  
258 three heights. Post hoc testing was performed where significant differences

259 were identified. Pairwise tests, with the Bonferroni adjustment were applied  
260 such that the criterion of significance was divided by the number of  
261 comparisons (3). Therefore a new criterion of significance ( $p < 0.017$ ) was  
262 applied to avoid spurious positive results [38].  
263

## Results

Following a physical assessment on each day of data collection, all 15 dogs recruited fulfilled the inclusion criteria and were eligible to participate. All dogs required no more than one acclimatisation jump in order to complete a successful trial. All fifteen dogs completed three trials at each of the platform heights. The distance between platform and force-plate that was set for each dog following a successful acclimatisation jump-down was recorded. In total, 135 successful jump-downs were recorded.

The first trial performed by subject one at the 0.55m platform was found to be invalid when retrospectively studying the raw data. Consequently, a mean value of the two subsequent valid trials completed by this dog, for this height, was calculated. All other 134 trials were valid and taken forward for analysis. An example of the GRF data for an individual subject can be seen in Figure 2. All peak limb forces reported are for pairs of forelimbs.

### *Vertical Ground Reaction Force (vGRF)*

Peak forelimb vertical ground reaction forces ( $F_z$ ) were significantly different between the different platform heights examined ( $F_{(2,28)}=89.749$ ,  $p = 0.001$ , partial  $\eta^2=0.865$ ; Figure 3). There was a significant difference ( $p = 0.001$ ) in forelimb vGRF from  $27.35 \pm 4.14\text{N/Kg}$  at platform height 0.55m to  $30.84 \pm 3.66\text{N/Kg}$  at platform height 0.65m. From platform height 0.65m to 0.75m there was also a significant difference ( $p = 0.001$ ) in vertical ground reaction force ( $F_z$ ) from  $30.84 \pm 3.66\text{N/Kg}$  to  $34.12 \pm 3.63\text{N/Kg}$ . Between the 0.55m and 0.75m platforms a significant difference ( $p = 0.001$ ) in vGRF was observed from  $27.35 \pm 4.14\text{N/Kg}$  to  $34.12 \pm 3.63\text{N/Kg}$ .

### *Craniocaudal Ground Reaction Forces (cGRF)*

296 There was no significant difference in peak forelimb craniocaudal ground  
297 reaction forces ( $F_y$ ) between the different platform heights examined  
298 ( $F_{(2,28)}=2.546$ ,  $p=0.422$ , partial  $\eta^2=0.154$ ).

299

300 *Mediolateral Ground Reaction Forces (mGRF)*

301

302 There was no significant difference in peak forelimb mediolateral ground  
303 reaction forces ( $F_x$ ) between the different platform heights examined  
304 ( $F_{(2,28)}=0.947$ ,  $p=0.400$ , partial  $\eta^2=0.063$ ).

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## Discussion

Despite evidence of injuries occurring in dogs specifically participating in agility [39], little is known about the epidemiology of other canine sporting injuries [40]; a consequence most likely of the paucity of quantitative research available [41]. A range of sporting activities, including hunting [42], and greyhound racing [43], are yet to be fully investigated with preliminary data suggesting that dogs may be at risk of injury. Dogs are routinely transported in vehicles to participate in sports and complete their daily exercise routines, yet the effect of jumping out of a car boot is unknown. It is also worthy of note that dogs jumping from a vehicle may have undergone an extended period of recumbency meaning that they lack the warm up that is essential for injury prevention [44].

Results obtained in this study indicated that over three progressively increasing platform heights, peak forelimb vGRF significantly increased. There was a 12.8% increase from platform 0.55m to 0.65m and a 10.7% increase with a further 10cm rise in height. Overall, the peak forelimb vGRF from lowest to highest platforms increased by almost a quarter (24.80%).

To the authors' knowledge, this is the first canine study investigating the kinetics of a static start jump. However, these findings concur with previous research relating to jump height [13, 15] and illustrate that even a relatively small increase in jump-down height can significantly alter landing kinetics. However, it is worthy of note that the changes in peak vGRF were smaller in terms of percentage increase (12.8% (0.55m to 0.65m) and 10.7% (0.65m to 0.75m)) than the increase in jump down height, which was 18.18% for the 0.55m to 0.65m height and 15.38% for the 0.65m to 0.75m height. It would be expected that peak vGRF would be higher when jumping from the higher platforms due to the increased length of the aerial phase and the consequent change in downwards velocity (due to gravitational acceleration) at impact [13]. Jumping from a higher height could result in a steeper landing angle, which has been shown to correlate with increased peak vGRF and impulse in dogs

372 jumping hurdles [13]. Considering this, peak vGRF increased comparatively  
373 less with increasing jump down height than might be expected.

374

375 Given that loading cadaveric forelimbs has resulted in significant changes  
376 ( $p < 0.05$ ) in humero-radio-ulnar congruency [26], particularly at 100% of  
377 bodyweight, it follows that when jumping down repeatedly from a vehicle boot,  
378 internal structures of the locomotor system are subject to increased loading.  
379 This might contribute to the higher risk of injury observed in agility dogs [39]  
380 who are transported frequently to training and competition events and to dogs  
381 who perform this task as part of their working role. In this study, the exclusion  
382 of dogs below 0.43m in height at the withers enhanced cohort homogeneity  
383 permitting more accurate comparisons. Further research should take place to  
384 confirm that these findings are consistent with smaller but equally popular  
385 breeds of dog. This could nevertheless be ethically problematic, given the  
386 known significant variance in temporospatial and kinetic variables between  
387 small and larger breeds [45].

388

389 The lack of any significant effect on mediolateral GRF seen in this study is  
390 perhaps a demonstration of the lack of variance in sagittal movement when  
391 landing on a perfectly level surface. Unlike cross-slope walking which can  
392 result in variability in mediolateral forces [46], dogs in this study were not  
393 required to markedly adapt to their landing conditions, given the force plate  
394 and rubber matting was level and stable. Furthermore, the dogs were not  
395 required to stop abruptly upon landing which would require more complex co-  
396 contraction of musculature [47] and increase the potential for multidirectional  
397 sway. There is a possibility that some dogs jumped slightly more to the left or  
398 right whilst still landing on the force plate. Further work is required to  
399 investigate jumping strategies in dogs and the effect of these on mediolateral  
400 forces. In addition, this study only reported peak mediolateral landing forces  
401 for paired limb contacts, which will not reflect that changes in body posture that  
402 occur throughout the duration of the stance period.

403

404 While most dogs were observed to continue to travel forwards under  
405 momentum, there was variance across subjects with some landing in an

406 efficient manner, coming to a halt only one or two footfalls later. This variability  
407 may explain the insignificant findings ( $p=0.422$ ) for the craniocaudal GRF data  
408 collected. In a domestic setting, both of these kinetic measures could vary if,  
409 for instance, a dog routinely jumps laterally away from a vehicle, perhaps  
410 towards the direction of a familiar building.

411

412 In this study, the highest mean peak vGRF was recorded to be 42.2N/Kg (at  
413 the 0.75m platform), which is directly comparable to the 45N/Kg vertical forces  
414 previously recorded of galloping dogs jumping over hurdles [13]. The forces  
415 sustained from a single jump in this study, therefore, have the potential to be  
416 withstood by the limbs, given that at gallop these forces can be exerted and  
417 absorbed during each galloping gait cycle [48]. In general, relatively few dogs  
418 jump hurdles or fences regularly, with those that do undertaking specific  
419 training techniques [39, 44]. Therefore, the comparable peak forelimb landing  
420 limb forces do suggest that consideration should be taken when allowing dogs  
421 to repeatedly jump from cars unaided.

422

423 This study did not attempt to investigate the consequences of vGRF on joints  
424 and soft tissues within the kinetic chain. As such, no evidence can be provided  
425 defining the relationship between the increased vGRF and potential injury.  
426 However, given the known variance in loading and viscoelastic properties of  
427 anatomical structures [49], failure will occur when loading limits are reached.  
428 This study only utilised healthy dogs, hence the data may not be applicable to  
429 all dogs, particularly those with pre-existing pathology that might affect their  
430 gait [50, 51].

431

432 One difference between the data collected in this study and jumping from cars  
433 is that some vehicles will have a raised boot sill relative to their compartment  
434 floor. In such circumstances, the dog would be performing a countermovement  
435 jump [52], albeit the ascension phase is relatively minimal. This could  
436 potentially reduce the landing distance, particularly given that there is no  
437 opportunity for significant momentum to be generated. Furthermore, the  
438 internal surface of a car boot (carpet, plastic) can differ in addition to the degree



439 of damping offered by different landing surfaces which may impact on limb  
440 loading patterns [53].

441

442 Many of the previous canine studies examining jumping have used agility dogs  
443 as their sample population [12, 27]. This study, although including some dogs  
444 with agility experience, also included non-agility dogs, since it was believed  
445 this would improve applicability of the findings to the companion dog. While  
446 most dogs were able to follow instruction readily, it was observed that one or  
447 two non-agility dogs performed several trials before it was perceived they had  
448 been accustomed to the requirements of the task. Although this habituation  
449 effect witnessed by other authors [54, 55] occurred, it is likely that its effects  
450 were negligible, since the hesitancy shown by dogs was witnessed prior to  
451 their jump-down but did not appear to change the mechanics of the jump itself.

452

453 This study provides the first objective evidence to support the commonplace  
454 belief that allowing dogs to repeatedly jump clear from vehicles with high boot  
455 compartments may be inadvisable. However, further work is needed to  
456 definitively link increased peak forelimb vGRF to common canine forelimb  
457 pathologies. Although at present relevant authorities do publish guidance over  
458 the safe transportation of dogs [2–4], methods of entry and exit into or out of  
459 the vehicle are not explicitly outlined. It is hoped that this paper will increase  
460 the awareness of the potential for harm and promote positive changes in  
461 canine husbandry.

462

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464

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466 public, commercial or not for profit sectors. The authors would like to thank  
467 Mark Cox for his assistance with data collection and all the dog owners who  
468 kindly allowed their animals to participate in this study.

469

## 470 **Figure Legends**

471

472 Figure 1. Experimental set-up depicting the platform (0.9m x 1.1m) from which  
473 dogs performed a static start jump down and the force plate. The area of the  
474 force plate is indicated with tape on the rubber mat. The height of the platform  
475 was adjustable and was set to either 0.55, 0.65 or 0.75m. The distance (d)  
476 from the platform to the plate was dependent on the individual subject and the  
477 range of distances used was from 0.26m to 0.47m (mean  $0.38 \pm 0.05$ ).

478

479 Figure 2. Force plate data from one dog. All trials are shown for each jump  
480 down height (0.55, 0.65 and 0.75m) with the mean overlaid (solid line).  
481 Summed vertical forelimb landing forces (Fz) for pairs of limbs is shown in  
482 green, summed craniocaudal forelimb landing forces (Fy) is shown in red and  
483 summed peak mediolateral (Fx) forelimb landing forces is shown in blue.

484

485 Figure 3. Mean (of the three trials at each jump down height) peak vertical  
486 forelimb GRF (Fz) for all subjects. Lines represent the median and diamonds  
487 represent the mean.

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